Project Title: Characterization of Green Roof Performance Parameters in the High Elevation, Semi-arid, Temperate Colorado Front Range Region.

Problem Statement: The Region 8 EPA's new office building possesses numerous sustainable design features, including a 20,000 square foot vegetated or "green" roof, that minimize negative impacts on the environment. Although green roof installations are abundant in Europe (in Germany 10 percent of buildings have green roofs), they are uncommon in North America (VanWoert et al., 2005) and few exist in the semiarid interior, encompassing Colorado's Front Range region (including Pueblo and Fort Collins, Colorado, and all area in between). Currently, there is a paucity of applied research specific to diverse regional climactic zones across North America; this is particularly true for high elevation, temperate, and semi-arid regions. It generally is believed that more site-specific empirical data are needed in order to understand and improve performance before green roof applications significantly increase throughout the United States (Connelly and Liu, 2005; VanWoert et al., 2005).

Review of the literature indicates that the application of this technology yields the following environmental benefits: filtration of air pollutants and atmospheric dust (Urbonas and Doerfer, 2003), reduction of smog formation (Stone, 2005), provision of wildlife habitat, conservation of energy, reduction of sewage system loads, improvement in quality of stormwater runoff, reduction of urban heat island effect, and improvement in urban aesthetics, ([1]U.S. Environmental Protection Agency). Such benefits of green roofs derive from the presence of living plants and soil medium, which mimic functions of natural landscapes.

Although the initial cost of a green roof installation currently is higher than that of a conventional roof, the lifetime costs are roughly comparable due to longer roof lifespan ([2]U.S.Environmental Protection Agency) and energy cost savings attributable to green roofs. In addition, decreases in stormwater load from green roofs may allow for scaled-down and more affordable conventional post-construction infrastructure necessary to meet local stormwater control ordinances. Relative to that of Europe, the cost of green roof installations in the U.S. currently is high; but as the U.S. industry matures, costs reportedly will decline ([2]U.S. Environmental Protection Agency).

Currently information on green roofs is primarily anecdotal, proprietary, or derived from research conducted in temperate regions where annual precipitation rates exceed 30 inches. In the Front Range, annual precipitation ranges between 10-15 inches (American Forests, 2001). Limited precipitation, high elevation, intense insolation, and extreme variations in temperature that typify our region are major plant stressors. Therefore, technology established in low elevation and humid climates is not directly applicable to the arid west. Consultation with local horticultural experts indicates that plant species selected for the R8 rooftop application, all within the genus *Sedum*, would likely require significant irrigation, which is considered to be an undesirable use for water resources in this region. Although many *Sedum spp.* are drought-tolerant, the degree to which they will require irrigation and adapt to the harsh environment on a rooftop in Denver remains open to question (Kelaidis & Klett 2005/ 2006).

This RARE proposal is a component of an overall research strategy to facilitate the development of this new green roof and to design a research strategy with our project partners. Because of the risk of roof failure from possible poor success rates of the selected species, the paucity of information on green roofs in this region, and the large potential for environmental results, we wish to conduct a study on various performance parameters of this green roof. With the advent of this new green roof in downtown Denver, we can seize this rare opportunity to develop baseline empirical data on green roofs in this region in order to optimize performance and to facilitate technology transfer in the arid west.

Research objectives: We propose three main objectives.

Objective #1- Biological Performance: For the roof to function properly in our semi-arid region and provide the primary anticipated environmental benefits, including stormwater and urban heat island mitigation and water conservation, the soil matrices and chosen plant species must be appropriate. Based on certain criteria, or lack thereof, we suspect that the sedum varieties selected for this installation are more appropriate for wetter climates and question their long-term survivability in this region. Empirical data on appropriate plants and planting media for green roofs in temperate, semi-arid regions are essentially lacking. Anecdotal information indicates that in extreme environments characteristic of this region, native plants are the best choice (Scalia, 2006). The *Sedum spp*. that have been selected for planting are not native to this region. Therefore, the first objective is to conduct horticultural experiments to select combinations of plant varieties and growth media that thrive with minimal irrigation, maintenance, and costs. Gaining biological performance data from site-appropriate plant varieties and soil matrices will significantly add to the knowledge base of this emerging field.

Objective #2- Stormwater Monitoring: In 1998, in metropolitan Denver 39 percent of the total land cover was classified as impervious (American Forests, 2001). Stream habitat impairments from altered hydrology and impaired water quality emerge when impervious surfaces within a watershed exceed 10 percent. Roofs may contribute significantly to total impervious surfaces; for example, in New York, NY, and Sacramento, CA, roofs comprise 18 percent and 20 percent, respectively, of the total impervious surface (Akbari et al., 1999; Rosenzweig et al., 2006). Because green roofs mimic the natural land cover function of absorbing water during precipitation events, we wish to monitor discharge volumes and water quality from our green roof and a conventional "control" roof. We will then evaluate the data to determine the effectiveness of green roofs as a best management practice for storm water control in our region. Because of the large relative component of roof surface area to total impervious land cover, there is a potential to significantly mitigate storm water impairments over time if green roofs are proven effective and become more commonplace in the region.

Objective #3- Heat Island: Because of the urban heat island effect, average temperature highs in high-density urban areas are significantly higher than that of surrounding low-density areas. This phenomenon, which peaks during increasingly frequent heat waves, is a growing environmental and public health concern, especially in large cities (Rosenzweig et al., 2006; Stone, 2005; Knowlton et al., 2004). Roofs significantly contribute to urban heat because of their high emissivity, or ability to reradiate absorbed solar radiation as infrared radiation (heat). There is a movement in numerous regions to increase the reflectance (albedo) of roofs by requiring light-colored roofing materials to reduce urban heat island (Rosenzweig et al., 2006). Recent studies have shown that green roofs are significantly more effective per unit area at mitigating urban heat island effects than high-albedo roofing material (Rosenzweig et al., 2006). Because urban heat island effect peaks on cloudless days (Rosenzweig et al., 2006) that typify this region, Denver potentially is an ideal location to study urban heat island mitigation parameters of green roof technology. Warm season temperatures on green roofs are reportedly much lower than that of conventional roofs by as much as 50 degrees centigrade (90 degrees Fahrenheit). Cooler roofs reduce warm season energy demand for air conditioning, resulting in two likely outcomes: reduced electricity demand on a regional scale and reduced urban heat island contribution from air conditioners on a local scale. The flux of waste heat emissions in urban areas can exceed solar input and may significantly contribute to urban heat island effects (Stone, 2005). For this third objective, we wish to obtain and evaluate roof temperature data to determine the effectiveness of the green roof at mitigating urban heat island effects and to model the theoretical reduction in the building's cooling load.

Approach: For Objective #1, the R8 U.S. EPA, as the lessee of the subject office building, has negotiated an agreement with the building owner to set aside 3,000 square feet of roof surface area for use as a green roof horticultural laboratory. We will divide this area into subplots of predetermined size (e.g., thirty plots of 100 square feet each) randomized across the roof to derive a statistical representation of the roof with an acceptable degree of confidence. The plots are to receive combinations of growth media, irrigation regimes, and selected plant species and varieties with adaptive traits that favor survival within the extremely broad range of expected environmental parameters. The plant species and varieties are likely to be indigenous to this region or introductions from regions with climatic and weather conditions similar to that of this region. Consequently, the species and varieties will no doubt overlap with, yet significantly extend the pallet of species and varieties already used in current green roof applications in regions with greater moisture levels or milder climates. Baseline data on biological performance of the *Sedum spp.* will be collected throughout the duration of the project.

Investigators will use standard methods to test selected plant varieties, soil matrices, and irrigation regimens. The project will document plant (biomass) production, cover, and species and varietals composition to identify an appropriate mix that is best adapted for survival on this roof. Once the optimal substratum and species and/or combinations of species are determined, we expect the vegetation cover will thrive with minimal maintenance and cost. Results thus obtained will inform the range of substrata, irrigation regimens, and species and varieties best suited for this roof, as well as future green roof applications within this region and other similar regions throughout the nation and the world.

Ancillary to the horticultural research, investigators will record weather conditions and irrigation volumes. These data will augment data requirements for Objectives #2 and #3. A weather station on the subject green roof and an adjacent conventional "control" roof will record weather conditions. Measured parameters will include temperature, relative humidity, wind velocity, and precipitation. These data sets from the green roof and control roof are required for all three Objectives.

For Objective #2, trapezoidal flume and bubbler automatic samplers (flow meters) placed in gutter downspouts will monitor and record runoff from rainfall and snowmelt. The precipitation gauge and flow meters will collect data at a minimum of 10-minute intervals. The three sets of data, from the subject and control roofs and precipitation gauge, are required for peak flow and runoff volume comparisons. We expect the data will support the hypothesis that the subject roof maximum flows will be lower and delayed as compared to that of the control roof and that the vegetation and planting medium will absorb a significant percentage of the precipitation. We intend to characterize those parameters for this region and this type of extensive green roof application and provide an empirical determination of stormwater discharges of the two roofs relative to total precipitation.

Water quality monitoring and assessment procedures include field sampling and testing of rainwater or snowmelt from subject roof runoff and from control roof runoff. EPA has proposed an agreement with a co-located building owner to monitor runoff volume and water quality from the roof of their building, sited adjacent to the new EPA building, as an experimental control for a period of two years.

Water samples will be collected using standard methods for environmental monitoring and assessment according to the parameters of interest, including, but not limited to, physical properties (pH, temperature, total suspended/dissolved solids), basic chemistry (hardness and alkalinity), nutrients (N and P), and metals (Cd, Hg, and Zn). The water samples may be analyzed at the EPA Region 8 laboratory. The empirical data from runoff and water quality studies will be used to calculate stormwater volumes and contaminant loads in runoff from the subject and control roofs.

The Urban Drainage and Flood Control District (UDFCD; managing drainage into the Southern Platte River Basin) plans to use results from these studies to assess the potential for green roofs as a post-construction best-management practice and to inform future Criteria Manual revisions. The UDFCD Criteria Manual, Volume 3, provides guidance for the selection and design of stormwater quality best-management practices. The three-volume set is a primary reference for stormwater professionals and civil engineers across the nation.

For Objective #3, roof top temperature data recorded at a minimum of ten-minute intervals will be used for analysis of urban heat island effect. These data are required for analysis of differences in diurnal temperature variations between the subject and control roofs. Temperature vs. time will be plotted to compare temperature flux differences between the two roofs. We anticipate that the temperature fluctuations on the subject green roof will be significantly modulated by the substratum and vegetation and that the temperature fluctuations on the conventional control (gravel) roof will exhibit a broad range in diurnal extremes. In addition, we will use temperature data and data on energy use of the new and control buildings to model theoretical reductions in building energy consumption and estimate theoretical energy fluxes in waste heat emissions.

Expected Benefits to the Region: We expect that this research will yield significant beneficial environmental outcomes on various scales. On the local and short-term scale, we expect to apply results from this project to characterize and optimize performance parameters of the subject roof. In turn, local interest in the near-term successful application of this technology suggests technology transfer will be rapid. For example, as stated above, the UDFCD will evaluate this technology as a standard post-construction best-management practice for stormwater management in the South Platte River Basin and use these data in future revisions of its Criteria Manuals. These studies will contribute to the greater body of information on green roof technology as applied to the arid west and beyond. There currently is a significant gap in empirical information on green roof applications as specifically applied to this region; we intend to fill this gap.

The first objective of this research, to identify plant species and varieties that will thrive with minimal irrigation, is critical. Literature references for plants suitable for this type of application in our region are not available at this time. Thus, the feasibility of this technology within this region hinges upon the proper plant assemblage. Identifying the appropriate plants is the first step in adapting this technology to high elevation, arid, and temperate regions and in demonstrating the viability of this technology. Survival of rooftop plants is prerequisite to realizing sustainable stormwater and urban heat island mitigation functions of green roof applications.

Project results will be disseminated through websites, scientific and trade journals, conferences, presentations, and building tours. Reports resulting from these studies will contribute to the greater body of information on green roof technology as applied to the arid west and beyond. Letters of support for the R8 green roof project from local government and water officials conveyed interest in advancing this technology. (See attachments.) Colorado's Governor's Office of Energy Management and Conservation has expressed considerable interest in supporting greenroof technology in the state. In terms of disseminating successes, recommendations, and lessons learned, they are interested in interacting with others in Colorado who are designing and or building high performance buildings.

Refinement of this technology has a high potential as a low-impact development method. High rates of population growth and accompanying development are ubiquitous across the U.S. Some of the fastest-growing communities in the nation are in Region 8, e.g., Douglas county most recently was the sixth fastest-growing county between the years of 2000 and 2005 (http://www.census.gov/population/pop-profile/dynamic/PopDistribution.pdf). Two regions within Region 8, the Wasatch Front (Salt Lake City, Utah region) and the Front Range, are highly urbanized and subject to water and air quality impairments, including high levels of ozone and particulate in the air. Rates of land development and redevelopment along with continued pressure to develop precious green space are steadily rising. With the refinement of this technology, developers and property owners, as well as local and state governments, will then likely have another economically feasible, low-impact development option. The literature asserts that green roof technology is kind to our land, water, and air, and through energy savings and maximization of land use, may prove economically preferable to conventional technology, especially when environmental values are factored into the long-term economic cost analyses (Banting, 2005). Green roofs contribute to healthy and livable environments in high-density development and Smart Growth designs, which are increasingly common in the region. Green roof applications are also compatible with Denver's *Greenprint* Program, which states the City and County of Denver's goals for sustainability, including the planting of one million trees. Within approximately ten years, through the voter-approved *FasTracks* Program, the region will add nearly 120 miles of transit, including light-rail and commuter-rail, with accompanying large extent of transit-oriented development. Green roof applications in combination with other low impact development options may significantly improve the quality of life for future residents within these developments while reducing the environmental impacts to our air, water, and land through voluntary compliance.

The green roof on the new Region 8 EPA office building will effectively be a satellite laboratory for the Region and for the Office of Research and Development. Establishing this collaboration with ORD will provide immeasurable benefits for the Region. The Region will require support from ORD staff on various fronts, including:

- Oversee research conducted and assume the role of project officer and/or work assignment manager.

- Provide guidance on issues of science and policy and guidance specific to laboratory operations as applied to this type of laboratory.
- Recommend and provide specialized expertise for planning research activities.
- Assess results and progress and facilitate decisions about future directions.
- Assess Regional science needs and support the needs of the regional science and technology laboratories to appropriately meet the science needs.
- Help establish partnerships with other Regions and state and private entities and facilitate the transfer of successful technologies.
- Peer review and publicize results in venues such as conferences, scientific journals, technical publications, etc.
- Serve as a portal for appropriate scientific expertise and information.
- Serve as a portal for data collection and analysis methods, protocols and guidance.

This proposed effort addresses two of the six regional priorities: energy and revitalization. Green roof technology is a component of green or sustainable building and Smart Growth. According to the Office of Solid Waste and Emergency Response web page (http://www.epa.gov/swerrims/landrevitalization/ai_fosteringsustainability.htm), green building and EPA's Smart Growth Program are components of Land Revitalization. This Project is in accordance with Region 8's Land and Water Revitalization Initiative and Draft Energy Strategy (http://www.epa.gov/region8/about/priorities.html#6). Furthermore, this project is in accordance with the Office of Research and Development's Draft Sustainable Research Strategy of May 4, 2006 (http://www.epa.gov/sustainability/releasepubcommt.html).

Project calendar and milestones: This project is a two-year project and will evolve over time. Data collection and reporting related to green roof performance will be evaluated for two years after notification of selection of this project for RARE program funding. The initiation of Objective #1 of this proposal hinges on the plant growing season in the region. Ideally, initial planting of test species and varieties should be from April through early June of a given year. If the project is not completely established by that time in 2007, the initial planting will either be in September or October, 2007, or in April or May, 2008, for the 2008 growing season.

Activities that commence in January, 2007:

- Respond to comments from the local Science Review Board and submit final draft of proposal.
- Complete grant procedures and establish partnership with ORD.

Activities that commence in March, 2007:

- Establish cooperative partnership to finalize the work plan, costs, quality assurance project plan, and the monitoring plan. The partnership will design and launch the website to report project progress and results.
- Complete Quality Assurance Project Plans for biological performance, stormwater monitoring, and urban heat island effect studies.

Activities that will commence in April, 2007:

- Install stormwater and weather monitoring equipment and begin collecting data.
- Determine suitable plant species and media.

- Initiate growth of experimental plant material and begin collecting baseline data on plant performance, stormwater monitoring and assessments, weather, irrigation water use, etc.

Activities that will commence in June, 2007:

- Determine experimental plot locations, establish experimental plant material, initiate field study.

Activities that will commence in April, 2009:

- Collect and summarize data, complete draft report.

Activities that will commence in May, 2009:

- Complete final report.

Participants: EPA ORD, National Risk Management Research Laboratory; Region 8 Office of Partnerships and Regulatory Assistance; Region 8 Office of Technical and Management Services, Regional Laboratory; Denver Region Urban Drainage and Flood Control District; and EPA Headquarters.

Budget:

- Personnel salaries: This includes salaries for a part-time principal investigator. This also includes salaries and possible tuition for junior researchers, e.g., graduate students, and compensation for consulting services from horticulture and plant specialists.
- Fringe benefits: Estimated as 25 percent of salaries.
- Travel: Field work and sampling.
- Equipment: Weather stations, infrared thermocouples, and storm water monitoring equipment.
- Supplies: Plant materials.
- Publication expenses: Web site maintenance and printing.
- Installation costs: Storm water monitoring equipment and weather stations, including rerouting and capping of gutters to capture storm water on the control roof.
- Overhead: Estimated as 23 percent overhead
- In-kind contributions: Additional time from partners, additional computer costs, analytical and technical laboratory services, EPA equipment including a flow meter/sampler, a trapezoidal flume, a wireless weather station and a mounted lock box installed on EPA's green roof per specifications, donated research plants and other materials.

BUDGET (ONE YEAR) TEMPLATE

Item	**Cost**	**In-kind Match**
Salaries & Fringe	$ 82,500	$ 50,000
Analysis		$ 30,000
Computer costs		$ 10,000
Travel	$ 2,000	
Equipment		$ 44,663
Materials and Supplies	$ 12,500	$ 15,000
Installation Costs	$ 3,000	
Overhead	$ 30,000	
Total	**$130,000**	**$149,663**

Region 8 contact:
Kathy Dolan, Project Manager
Office of Partnerships & Regulatory Assistance
EPA Region 8
303-312-6142

Laboratory Contact:
Thomas O'Connor, Environmental Engineer
EPA Office of Research and Development
National Risk Management Research Laboratory
Urban Watershed Management Branch
732-321-6723

References:

Akbari, H., L.R. Rose, and H. Taha. December 1999. Characterizing the Fabric of the Urban Environment: A Case Study of Sacramento, CA. Report No. LBNL-44688. Lawrence Berkeley National Laboratory, Berkeley, CA.

American Forests 2001. Regional Ecosystem Analysis of Metropolitan Denver and Cities of the Northern Front Range, Colorado. http://www.americanforests.org/downloads/rea/AF_FrontRange.pdf.

Banting, D., H. Doshi, J. Li, P. Missios, A.. Au, D.A. Currie, M. Verrati. October 31, 2005. Report on the Environmental Benefits and Costs of Green Roof Technology for the City of Toronto. Report by Ryerson University, Department of Architectural Science, Toronto, Ontario, Canada, for the City of Toronto and Ontario Centres of Excellence – Earth and Environmental Technologies (OCE-ETech). Project contact: Hitesh Doshi.

Connelly, M., K.K.Y. Liu. . May 1, 2005. Green Roof Research in British Columbia – an Overview, Greening Rooftops for Sustainable Communities. Washington, D.C. 5/5/2005. NRCC-48203.

Klett, J., 2005, 2006. Department of Horticulture and Landscape Architecture, Colorado State University, Fort Collins, Colorado. Personal communication. .

Kelaidis, P., 2005, 2006. Denver Botanic Gardens, Denver, Colorado. Personal communication. .

Knowlton, K., C Hogrefe, B. Lynn, C. Rosenzweig, J.E. Rosenthal, S. Gaffin, R. Goldberg, K. Civerolo, J.Y. Ku, P.L. Kinney. 2004. Climate-related Changes in Ozone Mortality Over the Next 50 Years in the New York City Metropolitan Region. Environmental Health Perspectives. V. 112. No. 15.

Rosenzweig, C., W. Solecki, L. Parshall, S. Gaffin, B. Lynn, R. Goldberg, J. Cox, S. Hodges. 2006. Mitigating New York City's Heat Island with Urban Forestry, Living Roofs, and Light Surfaces. Sixth Symopsiom on the Urban Environment AMS Forum: Managing our Physical and Natural Resources: Successes and Challenges J3.2.

Scalia, B. August, 2006. Green Extremes. Today's Facility Manager. http://www.todaysfacilitymanager.com/tfm_06_08_news4.php.

Stone, Jr., B. 2005. Urban Heat and Air Pollution. Journal of the American Planning Association. V. 71. No.1.

Urbonas, B.R., J.T. Doerfer, 2003. Technical Paper: Observations on Atmospheric Dust fallout in the Denver, Colorado area of United States. Urban Drainage and Flood Control District, Denver, Colorado. . http://www.udfcd.org/downloads/down_techpapers.htm.

[1]U.S. Environmental Protection Agency, October, 2000. Vegetated Roof Cover, Philadelphia, Pennsylvania. Office of Water (4203), EPA-841-B-00-005D (http://www.epa.gov/nrmrl/news/news042006.html).

[2]U.S. Environmental Protection Agency, Heat Island Effect Website. http://www.epa.gov/hiri/strategies/greenroofs.html.

[3]U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Land Revitalization, Fostering Sustainability web page. http://www.epa.gov/swerrims/landrevitalization/ai_fosteringsustainability.htm.

[4]U.S. Environmental Protection Agency, Region 8, Region 8 Priorities. http://www.epa.gov/region8/about/priorities.html#6.

[5]U.S. Environmental Protection Agency, Office of Research and Development. May 4, 2006 (Draft). . Sustainability Research Strategy. http://www.epa.gov/sustainability/releasepubcommt.html. . http://www.epa.gov/sustainability/Sustainability%20Research%20Strategy%20FINAL%205-4-2006.pdf.

VanWoert, N.D., D.B. Rowe, F.A. Andresen, C.L. Rugh, R.T. Fernandez, L. Xiao. 2005. Green Roof Stormwater Retention: Effects of Roof Surface, Slope, and Media Depth. Journal of Environmental Quality. V. 34: 1036-1044.